Assessment of landscape ecology of agricultural protection forest system at Beizang Town, Daxing County, Beijing

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Abstract: Based on theories of protective forests and landscape ecology, the reasonableness of structures and patterns of shelterbelt system at Beizang Town, Daxing County, Beijing were analyzed and assessed from the two scales of forest belts and networks, by integrating uses of field investigation, GIS and RS techniques. Results showed that the existent main belt (3-12 m in width) was too narrow, while the assistant belt (3-27.1 m in width) was too wide; the species composition of the existent shelterbelts was single, and the structures and patterns of the shelterbelt system were unreasonable. It is suggested that the structure of the main and the assistant belts should be changed, such as increasing the width of main belts, decreasing the width of assistant belt, and planting more mixed species, and the pattern with arbores in the middle and shrubs in the sides of belts could be taken into account. For the landscape structure of forest network after regenerating or reconstruction, the grid number of closed network should be 13 per km^2 and the minimum number of belts should be 34 per km^2. This study also testified that integrating GIS and remote technique with landscape ecology could provide an effective method for reasonable reconstruction of the structures and patterns of shelterbelts system.

Keywords: Beijing; Shelterbelts; Shelterbelt structure; Ecology landscape; Assessment
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Introduction

With the development of economy and the improvement of living level, people gradually paid more attention to the quality of living environment. Thus, at present, study and implication of agricultural protection forest emphasize more about the integration of ecological, social and landscape benefits. In China, in past five decades, the condition of shelterbelt has been greatly improved and its ecological, economic and social benefits have been fully exploited; yet, the irrational structure and mis-management are still severe problems in most regions. The conditions of existent shelterbelts should be estimated precisely in order to instruct scientific modification of shelterbelts.

In the past years, the ecological, economic and social benefits were individually studied. With the development of modern landscape ecology and modern protection forestry, it has been recognized that there exists an interaction and mutually promoting relationship between them on large scale. Thus, the integration of ecological, social and landscape benefits in estimating the landscape-eco-value of protective forest is a key to providing precise and scientific references for the reasonable planning and managements.

Landscape ecology assessment is the basis of planning, management and protection of landscape (Yan 1999). For more deeply analyzing the relationship between shelterbelt and relative landscape elements, the benefits and functions of shelterbelts in landscape have been extensively discussed, and the farmland shelterbelts are taken as corridors to study matter flow, energy flow, and species flow Forman *et al.*; Xu 1996). Protective forest is also regarded as a part of landscape forestry and it is an art which can produce a series of benefits, such as beautifying natural landscape, improving living environment, supporting firewood and wood, and raising economic incoming and biodiversity. With the comparison of the optimal and existent landscape indices of agricultural protection forest networks, Zhou *et al.* (1991) assessed quantitatively the reasonability of spatial distribution of existent farmland forest networks, so as to represent the main management direction of the existent farmland forest networks and provide reference for land-use planning of agriculture.

Beijing region is in dry sub-humid monsoon climate zone, with less rainfall and more windy days in spring and winter. Since 1970s, a number of shelterbelts had been planted in southeast Beijing to offer protection for production and living in agriculture region. As the increasing demand for mental civilization, it is of great significance to integrate the landscape benefits of those shelterbelts planted into the comprehensive study of ecological, economic and social benefits. This study focuses on the landscape-eco assessment of the agricultural protection forest in Beijing region.

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Study area

The study was conducted at Beizang Town, which is located in the southwest of Daxing County, Beijing and on an alluvial plain of Yongding River. Of 5 585.685 hm^2 total land area, the uncropped land including wasteland, unused land and wilderness is 876.88 hm^2. The average altitude is 30 m. Soil quality is very low, composed of grip, clay and silver sand.

The climate of the region belongs to the typical warm-temperate-semi-humid continental monsoon type. Annual average amount of precipitation is 568.9 mm, and 60%-70% of it concentrates in July, August and September. Sunshine time is 2 769.3 h per year, and the frost-free period is about 204d in the plain areas. The annual average temperature is 11.5 °C and the accumulative temperature of ≥ 10 °C is 4 143 °C. Annual amount of evaporation is 3 times as much as that of annual precipitation. Main wind directions are in north and northwest in spring and winter. More windy days, with high wind speed, presents in spring (Yue *et al.* 1997).

With the exception of the man-made forests of 1195.52 hm^2, there is no natural forest distributed in this area. Forest coverage is 21.41%. Most of the plantations are pure stands of *Populous tomentosa.* The total area of mixed forest of *Populous tomentosa* and *Robinia pseudoacacia* is 428.1 hm^2. The mean age of trees in the mixed forest was over nine and the oldest tree was 20 years old. The plantation includes shelterbelts and sheet stand. Total length and total area of the shelterbelts is 16.7502 km and 108.9845 hm^2 respectively; the total area of orchards in the sheet stand is 618.48 hm^2. The main species for those orchards are *Pyrus bretschneideri, Malus pumila, Prunus armeniaca,* and *Prunus persica.* And nursery area is 39.96 hm^2.

Methods

The measurement on reasonability and benefits of farmland shelterbelt system not only included number of networks, distribution of networks and the situation of closed net on large scale, but the direction, structure of individual shelterbelt and the disposition of tree species on small scale as well. The farmland forest network was assessed on different scales.

Principle of estimating landscape-eco-network construction

Assessment of landscape structure is on large scale, and it is not to estimate individual belt, but the integrity of whole shelterbelt system. Landscape benefit assessment includes ecology and aesthetics (Xiao *et al.* 1990; Zhang *et al.* 2001). For comprehensively assessing the shelterbelt network, the landscape layout of shelterbelt network must be assessed by estimating tree species groups, distance between belts and porosity and so on.

Analysis of each shelterbelt structure

The adaptive structure of shelterbelt is chosen according to the aim of silviculture, the needed function and local natural condition. Shelterbelt structure can be divided into three types: dense structure, permeable structure, and loose structure, based on the porosity (β) and permeability (α), (Cao 1985). In general, optimal porosity is from 0.25 to 0.30 (Jiang *et al.* 1989). The permeability and porosity of the shelterbelts measured at Beizhan Town was in range of 0.3-0.5, and 0.3-0.4 respectively. These shelterbelts have multi-landscape layers, which is advantageous to living and migration of animals and plants, and make farm shelterbelt eco-system more abundant and stable.

Landscape indices of farmland forest network

Agricultural protection forest is in a network state in agricultural field. Thus, layout of forest network in field landscape is described with network indices. The protection network system is composed of interconnected belts. The nodes of the system are at the junction of two or over two belts or at the endpoint of single belt. Belts are connected edges between nodes. Connectivity (Q), Circuitry(R), Ratio of belt to patch (F), and Dominance (D) are used to estimate and measure the layout of farm forest networks on landscape scale (Zhou *et al.* 1994; Sun *et al.* 1997; Zhang *et al.* 2001).

Ratio of belt to patch: It is an index for describing the abundance extent at the aspects of area and number of networks, which is a landscape index of measuring number of forest networks. It is expressed as follows:

$$F_0 = S_0 / A_0 \tag{1}$$

where, F_0 is reasonable ratio of belt to patch; S_0 is reasonable area of shelterbelt networks; A_0 is patch area to be protected in reasonable state.

Connectivity and circuitry: Formed condition is measured by connectivity and circuitry of forest networks, which is used to measure connecting and net state. When reasonable node number, which equals two or over two, is more over nine, and the max number of belts is a function of the number. The expression of reasonable node number is as follows:

$$\begin{aligned} L_{\max}(V_{b0}) = {} & 2\text{int}(\sqrt{V_{b0}})[\text{int}(\sqrt{V_{b0}})]-1+2[V_{b0} \\ & -\text{int}^2(\sqrt{V_{bo}})]-\text{sng}[V_{b0}-\text{int}^2(\sqrt{V_{b0}}),\ V_{b0} \geq 9 \end{aligned} \tag{2}$$

where, $L_{\max}$ is the max number of belts; V_{b0} is reasonable node number. And the expression of reasonable connection index is as follows:

$$Q_0 = \frac{[N_{b0} - (n-1)]}{L_{\max}(V_{b0})} \tag{3}$$

where, Q_0 is reasonable connection index; N_{b0} is sum of main belts and assistant belts in the reasonable state; n is number of patch to be protected.

The max-number of closed mesh networks is a function of reasonable node number of shelterbelt network. Its expression is as follows:

$$H_{\max}(V_{b0}) = [\mathrm{int}(\sqrt{V_{b0}}) - 1]^2 + [V_{b0} - \mathrm{int}^2(\sqrt{V_{b0}})] - \mathrm{sgn}[V_{b0} - \mathrm{int}^2(\sqrt{V_{b0}})] \quad (4)$$

where, $V_{b0} \geq 4$, while reasonable circuitry is expressed as follows:

$$R_0 = \frac{(N_{b0} + n - V_{b0})}{H_{\max}(V_{b0})} \quad (5)$$

where, H_{max} represents max-numbers of closed networks; R_0 represents reasonable node number of shelterbelt network.

The patches mentioned above mean to be blocks to be separated by belts, and each patch may be one or some land used types.

Dominance of forest network: It is an integrated index that measures the occupied area, belt number and their distribution evenness of belts in shelterbelt networks. The building of shelterbelts network increases not only the number of corridors in landscape, but also the number of patches. That is to say, the building of shelterbelts network improves heterogeneity and diversity of landscape. The larger value of the index indicates that the occupied ratio is larger. The smaller value shows that the occupied ratio is smaller. In other words, the smaller dominance shows that the number of forest network are not enough, or indicates that its distribution is not uniform. Its expression is as follows (Sun 1995):

$$D_0 = H'_{\max} + \sum_{i=1}^{m} P_i \times \log\ 2 P_i \quad (6)$$

$$H' = -\sum_{i=1}^{m} P_i \times \log\ 2 P_i \quad (7)$$

where, H'_{max} is maximum numbers of landscape diversity when the proportion of different land use type is the same; H' is diversity index, measured by Shanon-Wiener exponent formula; D_0 is the reasonable value of dominance; m is numbers of each land type in landscape; P_i is the proportion of each land use type in landscape.

All indices mentioned above, such as ratio of belt to patch and dominance of forest network, are main indices, while connectivity and circuitry are assistant ones.

Assessment of the spatial landscape pattern of farmland shelterbelt networks

The reasonable value of landscape indices is a fixed value in fixed natural condition and the spot. The assessment of landscape pattern for the existent forest network can be carried out by comparing the actual value with reasonable value of the indices.

On the basis of landscape ecology, the existent landscape indices of the farmland shelterbelt networks at Beizang Town were compared and analyzed by combining the remote sensing and GIS data with the field observations. By comparing the landscape indices between optimal and existent conditions, we can analyze the reasonability of the existent net landscape structure. The less difference between the two values indicated that the existent structure was more reasonable. In general, the results are different because of different natural situations and local conditions. Through research and practice, it has been proved that the network is optimal when relative error θ is 0.15 between existent condition and optimized condition in equal area (Zhou *et al.* 1994). Thus, the standard of θ_{F0}, θ_{D0}, θ_{Q0}, and θ_{R0} is 0.15.

Results and analysis

Ecological structure of the existent forest network

The agricultural protection forest, with less difference between structure and types of patches, was built on the basis of the unified planning experience from the 1950s to 1960s. The shelterbelts at Sangmafang Village were taken as a case to be assessed and analyzed. The two belts, which are crossing at right angles, are numbered as 1 or 2 apart. The basic conditions of No.1 belt and No. 2 belt were shown in Table 1 and 2. The No. 1 belt was composed of four rows of *Populus tomentosa* and five rows of *Robinia pseudoacacia,* and its width is 27 m. The No. 2 belt was composed of three rows of *P. tomentosa* and one row of *R. pseudoacacia.* Wind speed at 1 m from the main belt was measured eight times and the wind speed in open field was measured one time (Table 3).

By comparing the calculated results with optimal index value, No.1 belt was determined as permeable structure. Field investigation results showed that average clear-bole height of the belt was 2.5 m, that was too high, and the belt was not vertical to the main wind direction. Thus, the belt was judged as assistant belt; nevertheless, as its protecting objects are roads, its structure is loose structure. The width of the belt should be decreased and the renovation should be taken into account because it had reached the age of 16.

No.2 belt was permeable structure with a porosity of 0.32 and permeability of 0.85. In respect of local main wind direction, this belt was main belt, but its protective capacity was not enough due to the missing trees. Its structure should be regulated.

Table 1. Basic condition in No.1 belt

Sample tree number	Species	Diameter at breast height/cm	Tree height /m	Crown width/m		Plant and row spacing /m×m	Age /a
				East-west	South-north		
1	*P. tomentosa*	22.3	16.5	4.58	5.42	6.05×6.02	16
2	*P. tomentosa*	22.6	14.1	5.24	5.33	6.25×6.12	16
3	*P. tomentosa*	23.4	16.5	4.25	4.7	6.50×6.15	16
4	*P. tomentosa*	18	16	4.89	4.9	5.75×5.95	16
5	*P. tomentosa*	19.8	16.2	4.62	4.49	5.80×6.10	16
6	*P. tomentosa*	19.4	16.5	3.8	4.75	6.30×6.25	16
7	*P. tomentosa*	15.3	14	3.84	4.53	6.29×6.21	16
1	*Robinia pseudoacacia*	8	9.5	4.4	3.7	7.0×7.0	9
2	*Robinia pseudoacacia*	7.7	8.6	3.75	3.3	7.0×6.5	9
Average value of *P. tomentosa* parameter		20.11	15.69	4.46	4.87	6.13×6.11	16
Average value of *Robinia pseudoacacia* parameter		7.85	9.05	4.08	3.5	7.0×6.75	9

Table 2. Basic condition in No.2 belt measured

Sample tree number	Species	Diameter at breast height /cm	Tree height/m	Crown width/m		Plant and row Spacing /m×m	Age/a
				East-west	South-north		
1	*P. tomentosa*	14.1	11.4	4.24	4.93	6.26×5.84	11
2	*P. tomentosa*	13.7	10.2	3.67	4.11	6.01×5.86	11
3	*P. tomentosa*	14.3	10.6	3.49	3.28	5.82×6.37	11
4	*P. tomentosa*	11.2	8.2	3.41	3.96	6.36×6.04	11
5	*P. tomentosa*	13.6	10.7	3.45	3.96	6.08×5.91	11
6	*P. tomentosa*	18.7	11.7	3.69	4.73	5.85×5.98	11
7	*P. tomentosa*	15.1	11.1	3.62	4.51	6.13×6.09	11
8	*P. tomentosa*	11.3	9.7	3.18	3.34	6.05×5.93	11
9	*P. tomentosa*	11.8	9.9	3.04	3.05	3.12×6.01	11
10	*P. tomentosa*	17.2	10.1	4.49	4.31	3.08×3.02	11
Average value of *P. tomentosa* parameter		14.1	10.36	3.63	4.02	6.10×6.01	11

Table 3. Wind speed in No.1 and 2 belts

Belt number	Wind speed in open field/m·s^{-1}	Average wind speed at 1m from the main belt /m·s^{-1}
No.1 belt	3.6	1.28
No.2 belt	2.4	2.05

Table 4. Structural parameters of No.1 and 2 belts

No. of belt	$\overline{D}$ /cm	G_1 /m^2·hm^{-2}	G_2 /m^2· hm^{-2}	β	α
No.1 belt	20.11	22.5	60.82	0.37	0.36
No.2 belt	14.1	25.08	78.38	0.32	0.85

Notes: $\overline{D}$ -- average diameter at breast height; G_1 -- the sum of section area per hm^2 in the existent belt; G_2 --the sum of standard section area per hm^2 in the same age; β -- porosity; α -- permeability.

Assessment of landscape structure of the existent forest networks

Field investigation, remote sensing technique and CITYSTAR (GIS) were synthetically adopted for the measurement agricultural protection forest at Beizang Town on large scale.

The parameter values of agricultural protection forest network in reasonable condition at Beizang Town were measured according to the planning map with the scale of 1:10000 in the 1960s in Beijing Daxing Tianhe Farm (Sun *et al.* 1997). The forest networks were disposed along ditches, rivers and roads. And the run of belts were mainly from east to west and from south to north. In the experimental area, the main wind direction is northwest or north. So the belts that run from east to west were regarded as main belts. The standard length of main belt was 500 m and the length of assistant belt (run from south to north) was 300 m. Main tree species was *P. tomentosa*. By GIS of CITYSTAR, the area of patches was calculated. The total area of Beizang Town was 5 585.685 hm^2. There were 51 patches before forest network was built. After building, the number of patches was increased to 305. Mis-management, over-felling and mis-grazing destroyed reasonable forest network layout and the number of the existent patches separated by forest nets was decreased to only 98. As the experimental area was in the region with serious wind sandy disaster, the whole town should be protected. For the whole landscape, the patches protected should be 51 and area was 5 585.685 hm^2.

Structure parameters for the existent forest network were measured according to the land use map with the scale of 1:50000 drawn in 1994, which was inputted into the com-

puter with the digitizer. Based of the map of 1994, a new land use map with the scale of 1:10000 was drawn up in 1998 by investigation in field. The number of belts, number of nodes, length and width of belts, distance between belts, total area of landscape, number of land use types, number of closed nets and so on were calculated by CITYSTAR, then structure parameters of forest network were deducted (Table 5).

According to the parameters listed in Table 5, optimized landscape indices and existent landscape indices were calculated (Table 6).

Table 5. Parameter values of reasonable landscape structure and existent structure of forest network

Comparative items	Belt number	Area of forest network /hm^2	Node number	Closed network number
Optimized	947	421.536	640	348
Existent	295	108.985	272	50
Difference	652	312.551	368	298

Table 6. Comparison between indices of reasonable landscape and existent landscape of forest network

Comparative items	Connectivity (Q)	Circuitry (R)	Ratio of belt to patch (F)	Dominance (D)
Optimized	0.738	0.5898	0.0928	45.76%
Existent	0.365	0.504	0.0199	17.38%
Relative error(θ)	0.505	0.1455	0.7856	62.02%

From Table 5, it can be seen that the landscape structural indices for existent structure of forest network are much lower than those of reasonable structure, and such structure cannot bring the protective function of forest network into full play. On the landscape scale, the layout of forest network is disorder and landscape-ecological benefit is not high.

The results in Table 6 indicated that the overall layout of local agricultural protection network was not reasonable. The indices calculated are as follows: $F+\theta_F \times F_0 = 0.0338 < F_0 = 0.0928$; $D+\theta_D \times D_0 = 24.24\% < D_0 = 45.76\%$; $R+\theta_R \times R_0 = 0.5895 < R_0 = 0.5898$; $Q+\theta_Q \times Q_0 = 0.7378 = Q_0 = 0.738$. The existent belts cannot meet the needs due to the fact that distribution of belts is not even and numerous trees are missing from belts in many locations. The layout of some belts did not conform to the standard of the planning. The density of shelterbelts has been magnified by human and the occupied areas of forest network were magnified in equal benefits, which was not economical. The less connectivity indicated that closed condition of forest network was not enough, thus decreasing the landscape benefit.

Conclusion and discussion

Porosity and permeability of belt structure

The structure of the existent belts with the porosity and permeability of 0.32-0.37 and 0.356-0.854 respectively is only relatively reasonable in theory, Practically, however, the main belt with the width of 3-12 m is too narrow, while assistant belts with the width of 3-27.1 m is too wide. In addition, composition of tree species was simplex. Accordingly the structure of main and assistant belts should be regulated, and mixed tree species should be planted. The optimal belts structure should be that the coefficient of wind permeability is in the range of 0.3-0.5, and the porosity is in the range of 0.3-0.4. In practice, a pattern with trees in the middle and shrubs in the side should be used, while clear bole height of tree should equated to the height of shrub in mature state.

Integrating GIS and remote sensing technique with landscape ecology theory

Practical results testified that integrating GIS and remote sense technique with landscape ecology theory is an effective means. Landscape structural indices, such as ratio of belt to patch, connectivity, circuitry and dominance of forest network can be used to assess the landscape situation of protective forest network. The protection forest networks at Beizang Town, Daxing County, Beijing were assessed by the indices mentioned above. Results showed that the existent forest network layout on landscape scale was not reasonable and there were a lot of questions such as the missing trees or even with no trees in some segment, net grid magnified by human, and less number of belts. We suggest that the number of closed network should be 13 per km^2; mini-number of belts should be 34 per km^2.

Designing and planning on landscape scale

At the course of building protection forest system and reconstruction of protection networks, landscape should be regarded as an important scale. Multi-tree-species configuration should be planted for heterogeneity and stability of landscape.

Thinking of objects protected

We should depend on capacity of resisting windstorm and sandstorm for objects protected to select types of shelterbelts. For example, orchard, as a kind of land use type, is more stable and the capacity of resisting wind and sand of fruit trees is more faint, so its protection forest should be dense structure; while for roads and ponds and so on, their capacity of resisting wind and sand is more stronger, loose structure shelterbelts should be adopted.

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